09/889642
6/PRTS
09/889642 Rec'd PCT/PTO 18 JUL 2001
WO 01/39353 PCT/CA99/01100

# Universal Motor Head for Electrical Submersible Pump

This invention relates to an electrical submersible pump ("ESP") such as is used in oil well pumping operations. ESP systems consist, typically, of an assembled selection of modular, tandem pump and motor components from an inventory of components. The modular tandem motor components in the inventory, as supplied by international ESP manufacturers today, typically may include one or more of an Upper Tandem Motor ("UT"), a Centre Tandem Motor ("CT"), and a Lower Tandem Motor ("LT"). The present invention provides a Universal Motor Head ("UMH") which facilitates a broader scope of use of the CT and LT components.

## Background of the Invention

An ESP is a pump that is designed to provide a pressure differential across its length at an optimized fluid flow rate. ESPs are designed and manufactured for installation within narrow diameter casings; generally pumps are between 3.38" and 10.5" in diameter and motors are between 3.75" and 7.38" in diameter. They are used to produce fluids such as oil, water and liquid gas and are predominantly applied to the international oil fields.

Presently, ESP manufacturers offer a wide variety of component products that are combined to make a working ESP system. An ESP will commonly consist of a threaded pump head for tubing connection, pump section (single or multiple tandems), intake section, motor protector / seal section, motor section (single or multiple tandems) and a motor base (separately mounted or factory installed) with an internal winding connector.

Power is supplied to the ESP motor through a cable that runs from the surface power supply facilities to the motor, where the power cable enters the motor through a dedicated connection port that is at the top of the upper motor. The end of the main power cable has a dedicated connector, commonly referred to as a 'pothead', and the dedicated motor connection port is commonly referred to as a 'pothole'. The pothole is generally of the largest size possible to fit within the constraints of the overall motor diameter and is normally only suitable for the specific type of motor being applied.

The reservoir characteristics and the volume of fluid being produced determine the motor horsepower requirements for ESP operation. In high pressure or high flow rate pump applications, horsepower requirements may exceed the amount available from a single section motor. Single section motor sizes are limited by their required relatively small external diameter

(to fit the drill hole) and the maximum transportable length of about 35 feet per section. Motors are therefore designed to be connected together to increase the available horsepower. Generally, the individual motor sections are specified with the same horsepower, voltage and current ratings. For example, if a pump requires 300 hp to operate, then two sections of 150 hp or three sections of 100 hp motors would be assembled in series (or in tandem) to meet the demand.

An ESP in use today may consist of a Single Section Motor ("STD" - for "standard"), which is made as a complete, stand alone unit for single motor applications, or may consist of one or more tandem motors. A tandem motor is made to be used in conjunction with one or more other tandem motors. The tandem motors currently available include the above-noted UT, LT and CT.

The UT has a wound stator, at its top an integral head with a flange for connection to a seal section / protector and an external cable entry port for a power cable connection and at its bottom an integral base with a flange connection with internal power connection terminals for connecting to the top of a CT or LT in multiple (tandem) motor applications. If it is desired to operate the UT as a single motor, then a universal motor base ("UMB") may be used to close the internal power connection terminals at the bottom of the UT. A UMB has power connection terminals at its top and forms a 3-phase Y-Point internally.

The CT has a wound stator, at its top an integral head with a flange with internal power connection terminals for connection to the bottom of another CT or to the bottom of a UT, and at its bottom an integral base with a connection flange with internal electrical terminals for connection to the top of another CT or to the top of an LT. A UMB may also be connected to the bottom of a CT if the CT is to be the bottom unit of a tandem motor unit, i.e. if it is to be used as if it were an LT. A CT type motor does not have an external cable entry port and cannot presently be used as the top unit of a tandem motor unit.

The LT has a wound stator, an integral head at its top with a flange with internal power connection terminals for connection to the bottom of a CT or UT, and has internal factory connected windings at the bottom to complete the three-phase power circuit and end the tandem unit. The LT can, therefore, presently only function as a lower unit of a multiple motor unit.

It is apparent from the foregoing that, if a tandem, multiple section motor is required, then an UT motor must be used to facilitate connection of the main incoming power cable.

There is, therefore, a need for a device which would expand the useful capabilities of CT and LT motors without the requirement for use of an UT motor to complete an ESP of modular

assembly. The prior art has not addressed this need, as is apparent from the discussion below of two United States patents relating to tandem motor assemblies.

United States Patent No. 3,255,367 discloses a multiple section motor assembly which has end termination units that cover the open ends of the assembly and contain elements for improving operation of the assembly. However, this patent discloses a fully integrated motor assembly which can only be assembled in a factory and is designed for application in a specific layout with no flexibility to change the assembly order of component parts. Thus, the motor units and end termination units are only modular parts in so far as final assembly must take place at the well site. They are not modular with respect to the interchangeability of the upper and lower motor sections. In this case the top section must always be a motor with a power cable connection port. Thus, these are not true modular components, for addition and removal depending on needs at the drill site, but rather are factory installed with a dedicated motor 'head' using complex components of an assembly intended to be shipped and used without modification at the drill site. For example, one end termination unit contains means for circulating a coolant throughout the assembly, a thrust bearing device for supporting the entire thrust load of the assembly during its operation, and a pressure balancing device. It is apparent that this patent does not teach towards a simple, modular device for easy installation and removal as an inventory item of a modular tandem motor system for making ESPs at a drill site.

United States Patent No. 3,384,769 is directed to a submersible pump assembly including a plurality of motor modules. The number of motor modules in an assembly may be chosen to provide the power out-put required. The motor modules are releasably connected together at their adjacent ends, via intermediate electrical connectors, so that the horse power rating of the assembly may be readily changed merely by adding or subtracting a standardized motor module without having to provide a different length of casing. The assembly includes an "auxiliary module" (in some respects similar to a modern day Protector / Seal Section), a complex device with several functions including equalizing pressure between the motor and the annulus, separation of the motor oil from the well (production) fluids, absorbing the thrust loading from the pump, and transfer of power generated by the motor to the pump. The auxiliary module is shown connected to a motor module by a connecting member, the latter being permanently attached at one connection to the auxiliary module but detachably connected (with the auxiliary module) to a motor module at another connection. The connecting member is partly designed to electrically connect the windings of the motor module to a three wire cable which leads to a three phase power supply for the entire assembly. It also accommodates a connection between the

drive shaft of a motor module and the auxiliary module. Since the connecting member is a permanent part of the somewhat complex auxiliary module, it is necessary for the entire auxiliary module to be used at the upper end of an assembly according to the teachings of this patent. Stockpiles of auxiliary modules would be costly to develop and would result in similar problems posed by the required use of UT units in tandem motor assemblies. Furthermore, the auxiliary module is not able to be connected in tandem with another auxiliary module, for example to increase the fluid pressure equalization facility, due to the permanently attached connecting member.

There is a need in the ESP art, therefore, for an element which will enable a low cost utilization of existing stockpiles of CT and LT units without having to use UT units, or other costly, complex units.

Summary of the Invention

The invention provides a motor head for detachable attachment to a centre tandem motor or a lower tandem motor of a modular electrical submersible pump at a well site. The motor head comprises a first mechanical connector means configured for detachable attachment of the motor head at the well site to a top of a centre tandem motor or a top of a lower tandem motor. There is also a second mechanical connector means configured for detachable attachment of the motor head at the well site to a bottom of a protector / seal section. Preferably, the first and second mechanical connector means are flange-type connectors. There is also a rotatable shaft configured for power transfer from the centre tandem motor or the lower tandem motor to the protector / seal section. There is a first electrical connector for electrical connection to an electrical power source for the pump. Preferably, the first electrical connector is a plug receptacle with side walls at an angle from vertical of about 5° to 30°, more preferably about 10° to 15° and most preferably about 12° to 13°. There is a second electrical connector for electrical connection to either the centre tandem motor or the lower tandem motor. There is, further, an electrical conduit to convey electrical power from the first electrical connector to the second electrical connector. The motor head also comprises a pressure-equalization fluid conduit for between the centre tandem motor or the lower tandem motor and the protector / seal section.

The universal motor head ("UMH") of the invention therefore may be used to close the internal power connection terminals at the upper end of a CT or LT. The inventive UMH has internal power connection terminals at the bottom, for connecting to the top of a CT or LT, and

port for external power cable connection at the top. An advantage of a UMH is that a CT with a UMH can be used as if it were a UT, and an LT can be used as if it were a single motor unit. The greatly enhanced versatility of the CT and LT units obtained with the UMH, particularly CT type motors in conjunction with UMB units, can lead to reduced motor stocks and operating costs.

## Description of the Drawings

Figure 1 schematically illustrates ESP modular motor components available currently from international manufacturers;

Figure 2 schematically illustrates standard motor string configurations based on the motor components of Figure 1;

Figure 3 schematically illustrates a UMH of the present invention and two applications;

Figure 4 shows a cross-sectional view of a UMH of the present invention;

Figure 5 shows a cross-sectional view of the UMH of Figure 4 including three transverse sectional views thereof; and

Figure 6 shows a three dimensional perspective view of the UMH of Figure 4.

## Description of the Preferred Embodiments

The following description relates to one preferred embodiment of the present invention and is, therefore, not intended to be limiting of the scope of the invention as defined in the claims herein.

With reference to prior art Figure 1, there is shown a STD motor, a UT motor, a CT motor and a LT motor. Beside each is shown the corresponding electrical wiring configuration. The STD motor is factory assembled as a complete unit for single motor applications. It cannot be used with other motors. It has a pothole in the head for power cable connection and the bottom windings are internally connected at the factory.

The UT motor is factory assembled with internal power connection terminals at the bottom. It has a pothole for power cable connection and, unless the present invention is used, must be used as the top motor when tandem motors are required. It can be used as a complete unit for single motor applications if a UMB is added.

The LT motor is factory assembled with internal power connection terminals at the top. It does not have a pothole for power cable connection and must be used as the bottom motor when tandem motors are required. The bottom windings are internally connected at the factory.

The CT motor is factory assembled with internal power connection terminals at the top and bottom. It must be used as the centre motor when tandem motors are required. It can be used as the lower tandem motor when a UMB is added.

The UMB attaches to the base of a motor and forms a three-phase Y-point.

Figure 2 illustrates conventional, i.e. prior art, string configurations using the components described above and shown in Figure 1. It is apparent that only a UT motor may be used as the top motor of any string.

Figure 3 illustrates application of the UMH of the invention in two exemplified configurations. The UMH is manufactured and factory assembled preferably with internal power connection terminals at the bottom. It preferably has a pothole for power cable connection at the top and is designed for connection to the top of a CT or LT motor.

With reference to Figure 4, in a preferred embodiment of the present invention the Universal Motor Head (UMH) consists of the main body 1 which has flange-type connections and 'O' ring seals for attachment to a protector / seal section at the top 2 and a tandem-type motor at the bottom 3. The body 1 may be made of any of a wide variety of materials, but preferably may be made of carbon steel, stainless steel, or monel. A protector / seal section is a separate piece (not part of the present invention) which, absent the present invention, attaches to the top of a motor and contains an oil reservoir for the motor. As background, it is noted that the protector / seal section is designed to:

a) equalize pressure between the motor and the surrounding well bore (the average oil well pressure may be at 2500 psi, but the motor is assembled at surface pressure of about 14 psi; it cannot simply be sealed against invasion of well fluid under well pressure);

b) minimize contamination of the clean motor oil by the dirty well fluid by using a combination of Positive Seal (elastomer rubber bags that have motor oil inside and well fluid outside - separated by a non-return valve) and Labyrinth (a long convoluted flow path that allows well fluid / motor oil contact but that relies on different fluid gravities for separation) sections; and

c) transfer power up to the pump sections through a central shaft; and

d) incorporate a thrust bearing to absorb the down thrust load generated by the differential pressure across the pump sections(s) above.

All segments of ESP's currently are joined using bolted flanges. The number of bolt holes may vary, but the basic form is generally the same. The upper end of the UMH preferably therefore has a head that extends upwards to form a flange with as large an outside diameter as possible, and the inside diameter is determined by the O-ring seal that is being used, and has a smooth finish. The top of this flange preferably is drilled and tapped for the bolts that will typically be used to secure to the upper protector / seal section. The bottom flange preferably is machined with a protruding shoulder that fits inside the lower head, i.e. inside the flange of the upper end of the lower motor unit. This shoulder may be machined with one or more grooves for 'O-ring' seals. The bottom flange has slightly larger holes drilled that will line-up with the holes drilled and tapped in the upper flange of the lower unit. The upper and lower flanges each include a central hole for accommodating passage of a drive shaft 4 from the motor up to the driven system.

The UMH of the present invention, which intervenes between a protector / seal section and a motor, has the central shaft 4 for power transfer through the head. The central shaft is configured, e.g. with spline or key, for coupling to a shaft of the motor below and a shaft extending to a system to be driven above. The shaft 4 preferably is supported by shaft bearings or bushings 5 and isolated from the internal wiring by a guard tube 6. The shaft bearings or bushings 5 are in direct contact with the motor fluid and are both cooled and lubricated by such fluid. The UMH includes an internal flow path (not shown), e.g. formed by drilling one or more through holes from top to bottom, for motor fluid from the motor unit below to the protector / seal section above. This ensures free movement of motor fluid in response to changing pressure.

In a typical ESP, the protector / seal section includes a thrust bearing to take the thrust loads transferred downwards from the pump shaft. Thus the UMH does not require a thrust bearing. The only load on the UMH is that from the mass of the shaft; the differential pressure between the two ends of the shaft being nominal. The underlying motor assembly is supported by the bearing at the top of the motor, thus the weight of the UMH shaft will ride on the motor bearing.

The UMH has a pothead attachment port 7 (or "pothole") for connection of a main incoming power cable, and internal cabling 8 to facilitate transfer of power from the pothead to preferably internal motor connectors 9 of which one generic phase (of three) is shown in Figure 4. The actual size of the pothole may vary. Preferably, the port 7 has side walls angled from vertical at from about 5° to 30°, more preferably about 12° to 18 °and most preferably about 15°, and has a lower face at right angles to the side walls. Sealing of a pothead in the porthole

may be by use of an 'O' ring and a dedicated 'O' ring groove on the outside diameter of an extended pothead face. The UMH can be adapted to work with "tape-in" or "plug-in" connectors. Both types fit within the recess in the UMH without protruding past the the outside diameter of the motor. As these each typically include three connectors for three phase power, these are preferably connected in use to a low profile parallel conductor (a flat cable to fit between the ESP and the side of the bore hole) that runs up to the main power cable.

The field attachable UMH of the present invention is unique in that:

(a) The UMH allows a CT or LT type motor to be connected, as the top motor section, to a protector / seal section. Such was not possible prior to the present invention as CT and LT type motors do not have a power connection port for main power cable connection;

(b) When attached to a CT or LT type motor the UMH will convert the function of the assembled unit to that of an UT or Single Section STD type motor respectively;

(c) The UMH has an integral connection port (pothole) for attachment of a power cable pothead, which enables main power cable connection. Prior to the present invention this type of connection port was only available on UT type motors, which had to be used as the top motor component;

(d) The UMH is a separate component part that can be attached to a CT or LT motor either during manufacture, maintenance in a workshop or during final assembly at the well site (field);

(e) The UMH readily allows the end user to combine motors and protector / seal sections from different manufacturers, which is normally not possible due to flange size and bolt pattern, 'O' ring seal size and type, electrical connection layout and termination type and shaft size and spine type incompatibilities.

The UMH allows ESP operators to meet their needs by stocking a relatively small number of universally applicable CT motors, UMHs and UMBs. It also allows ESP users to standardize their motor types and sizes and significantly to reduce overhead associated with running and stocking ESP equipment. A stock of CT motors, in which each CT motor effectively is a "universal motor" that has the flexibility of being used as a UT, CT or LT motor, thus eliminates the need to purchase dedicated motor types.

The UMH is preferably designed to be compatible with all ESP designs for connection flange types and configurations, electrical connection and shaft connection types and sizes. The UMH preferably is therefore capable of adapting from any type of ESP motor to any type of protector / seal section, regardless of manufacturer. It follows that the UMH allows ESP

operators the option of mixing different manufacturers' equipment, thereby increasing the flexibility of ESP stocks.